UNIVERSITI PUTRA MALAYSIA

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By

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EFFECTS OF HYDRAULIC LOADING RATES ON SEWAGE TREATMENT EFFICIENCY OF CONSTRUCTED WETLANDS

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Chairman : Katayon Saed, PhD

Faculty : Engineering

Constructed wetlands have been used as an alternative option to treat wastewater. The adaptation of natural system has attracted researchers to use it considering its many advantages of environment friendly, cost and energy saving. Constructed wetlands have also been introduced in Malaysia, but since it is a new development, more studies should be carried out to support its implementation to suit Malaysian condition. In this study, a functional pilot scale of constructed wetlands to treat domestic wastewater was designed and constructed. The main objective of the study is to determine the effect of different hydraulic loading rates (HLRs) on the treatment efficiency. Wetlands were designed and constructed inside the engineering complex, Faculty of Engineering, UPM.

There are three cells of constructed wetlands, all built in equal dimension, two cells were planted with *Lepironia articulata*, an indigenous Malaysia aquatic plant, known to be capable to remove pollutant from water, while one cell left unplanted to investigate the role of the plant in treatment process. Those cells were operated at

four different HLRs in 2 phases e.g. 32, 16, 5.33 and 2.29 $cm^3/cm^2/d$ which corresponding to hydraulic retention time (HRT) of 0.5, 1, 3 and 7 days respectively. Influent and effluent from each cell were then brought to laboratory to be tested. Parameters tested are pH, temperature, chemical oxygen demand (COD), total suspended solid (TSS), total phosphorous (TP), total ammonia nitrogen (TAN), nitrate, nitrite, total inorganic nitrogen (TIN), total coliforms, cadmium, copper, nickel, lead and zinc.

The results show overall removal rates of 50.18 to 88.49% for TSS, 56.77 to 77.62% for COD, 39.67 to 88.68% for TP, 27.50 to 98.79% for TAN, 27.23 to 96.34% for TIN and 3 to 4 orders of magnitude for total coliforms. It was found that HLR has significant effect on removal of COD, TP, TAN and TIN, while the existence of plant only has effect on nitrogen removal, and TP when it was set at long retention time in Phase 2 (3 days). Effluents from constructed wetlands met requirements of Standard A of discharge standard for Malaysia, meaning that the effluents were safe to be discharged to any inland waters.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KESAN KADAR MUATAN HIDRAULIK KE ATAS KEBERKESANAN RAWATAN KUMBAHAN NAJIS DI DALAM TANAH BENCAH BINAAN

Oleh

FIONA ZAKARIA

Ogos 2006

Pengerusi : **Katayon Saed, PhD**

Fakulti : **Kejuruteraan**

Tanah bencah binaan telah digunakan sebagai suatu pilihan alternatif untuk merawat air kumbahan. Penyesuaiannya terhadap sistem semula jadi telah menarik minat penyelidik untuk menggunakannya. memandangkan kebaikannya dari segi mesra alam serta penjimatan kos dan tenaga. Di Malaysia, tanah bencah binaan telah diperkenalkan dan ianya masih dianggap pembangunan yang baru. Dengan itu, kajian yang lebih banyak perlu diusahakan demi menyokong penggunaannya yang seiring dengan situasi Malaysia. Dalam kajian ini, tanah bencah binaan dalam skala utama fungsian untuk merawat air kumbahan domestik telah direka dan dibina. Tujuan utama kajian ini adalah untuk menentukan peranan kadar pembebanan hidraul (HLR) yang berbeza terhadap efisiensi rawatan. Tanah bencah yang direka ini dibina di Komplek Kejuruteraan, Fakulti Kejuruteraan, UPM.

Terdapat tiga sel tanah bencah binaan dan setiapnya dibina dalam dimensi yang sama, dua sel ditanam dengan *Lepironia articulata*, sejenis tumbuhan air asli Malaysia, yang diketahui berupaya untuk menyingkirkan bahan – bahan tercemar dari air. Manakala satu lagi sel dibiarkan begitu saja tanpa ditanami dengan sebarang

tumbuhan, bertujuan untuk menyiasat peranan tumbuhan dalam proses rawatan ini. Sel – sel ini dioperasikan pada empat HLR yang berbeza dalam 2 fasa, yakni 32, 16, 5.33 and 2.29 $cm^3/cm^2/d$ yang sama dengan tempoh penampungan hidraul (HRT) selama 0.5, 1, 3 and 7 hari menurut turutan yang awal tadi. Setelah itu influen dan efluen daripada tiap sel dibawa ke makmal untuk diuji. Parameter - parameter yang terlibat untuk diuji adalah pH, suhu, keperluan oksigen kimia (COD), jumlah pepejal terampai (TSS), jumlah fosforus (TP), jumlah ammonia nitrogen (TAN), nitrat, nitrit, jumlah nitrogen tak organik (TIN), jumlah coliform, kadmium, tembaga, nikel, timah dan zink.

Hasil penyelidikan menunjukkan purata kadar penyingkiran sebesar 50.18 sampai 88.49% untuk TSS, 56.77 sampai 77.62% untuk COD, 39.67 - 88.68% untuk TP, 27.50 sampai 98.79% untuk TAN, 27.23 sampai 96.34% untuk TIN dan dalam 10 pangkat 3 hingga 4 untuk jumlah coliform. Didapati bahwa HLR mempunyai kesan signifikan terhadap penyingkiran COD, TP, TAN dan TIN, manakala kewujudan tetumbuhan hanya berkesan pada penyingkiran nitrogen, dan TP saat ianya beroperasi pada tempoh tampungan yang lama yakni lebih dari 3 hari. Efluen daripada tanah bencah binaan mampu memenuhi persyaratan Standard A, standard buangan air untuk Malaysia, bermakna efluen dapat dibuang ke mana – mana perairan.

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And to these people I owe my life, to my father and mother.

I certify that an Examination Committee met on August 10, 2006 to conduct the final examination of Fiona Zakaria on her Master of Science thesis entitled "Performance Study on Subsurface Flow Constructed Wetlands in Treating Sewage" in accordance with Universiti Pertanian Malaysia (higher degree) Act 1980 and Universiti Pertanian Malaysia (higher degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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Date: 12 APRIL 2007

Table 2.2 : Previous Studies Using Different HLR/HRT

References	HLR ($cm^3/cm^2/d$)	HRT (d)	Dimension ***(l × w × d × n)****	Types	Plants	Source	Removal Efficiency	Remarks
Tanner et.al,1998	7.17 4.67 2.55 2.15	2.0 3.0 5.5 6.5	9.5 × 2 × 0.4 × 0.35	SSF	soft-stem bulrush (*Schoenoplectus tabernaemontani*)	Farm dairy wastewater		no direct relationship between HRT and accumulation of organic matter
Lin et al., 2002	1.8 2.3 3.4 6.8 13.5	4.4 3.5 2.4 1.2 0.6	5 × 1 × 0.4 × 0.4	FWS and SSF	FWS : *Ipomea aquatica* & *Paspalum vaginatum* SSF : *Phragmites australis*	Aquaculture wastewater	NH_4-N 86 Š 98% TIN 95 Š 98% P 32 Š 71%	HLR positively affected NH_4-N and TIN removal, negative at P.
Schulz et al., 2003	102.86 308.57 514.29	7.5 h 2.5 h 1.5 h	1.4 × 1 × 0.7 × 0.45	SSF	*Phragmites australis*	Rainbow trout farm effluent	TSS 95.8 Š 97.3% COD 64.1 Š 73.8% TP 49.0 Š 68.5% TN 20.6 Š 41.8%	No influence of HRT at TSS and COD removal, while TP and TN were negatively correlated with HRT (the shorter HRT the higher removal efficiency).
Garcia et al., 2004a	2 2.7 3.6 4.51	10.00 7.41 5.56 4.44	55 m^2 × 0.5 × 0.4	SSF	*Phragmites australis*	Urban wastewater	COD 62 Š 79% BOD_5 53 Š 84% NH_3 24 Š 51% DRP 0 Š 22%	HLR positively affected COD and BOD_5 removal but negative at NH_3 and DRP
Solano et al., 2004	15 7.5	1.5 3	20 × 2 × 0.4 × 0.59	SSF	*Typha sp.* & *Phragmites sp.*	Domestic wastewater	BOD 63 Š 93% COD 48 Š 90% TSS 58 Š 93% Total Coliforms 40 Š 99%	A significant relationship between percentages of removal and HLRs

Table 2.2 (Continued)

References	HLR ($cm^3/cm^2/d$)	HRT (d)	Dimension ***(l × w × d × n)****	Types	Plants	Source	Removal Efficiency	Other important notes
Lee et al., 2004	12	4.3	9.5 × 2.6 × 0.65 × 0.79	SSF	*Eichornia crassipes*	Pretreated swine wastewater	COD 77 Š 84%	Removal mechanism (from biggest contribution to lowest) SS : physical COD : physical Š microbial TN : physical Š microbial Š nitri/denitrification Š stripping Š assimilation Š plant uptake TP : physical Š microbial Š plant uptake
	6	8.4					TP 47 Š 59%	
	3.5	14.7					TN 10 Š 24%	
Huett et al., 2005	8.26	3	0,6 × 0.37 × 0.3 × 0.83	SSF	*Phragmites australis*	Plant nursery run off	Planted wetlands: TN & TP >96%	Satisfied with 3.5-day reaction time No effect of changing HRT
	3.54	7					Unplanted wetlands <16% N ; <45% P removal	
Ingersoll and Baker, 1998	5 10 20	3 1.5 0.75	0.2 × 0.13 × 0.15 × 1	SF	None	Tap water augmented with potassium nitrate (KNO_3)	Nitrate 8 - >98%	Increasing HLR caused decreasing efficiency

Table 2.2 (Continued)

References	HLR ($cm^3/cm^2/d$)	HRT (d)	Dimension ***(l × w × d × n)****	Types	Plants	Source	Removal Efficiency	Other important notes
Huang et al., 1999	1.80 2.70 4.00	2.6 3.9 5.9	0.52 × 0.36 × 0.42 × 0.5	Laboratory scale SSF	Woolgrass *(Scirpus cyperinus)* & Cattail *(Typha latifolia)*	Septic tank effluent	NH_4^+ 18.1 Š 39.0% TKN 31.3 Š 45.8%	Plant species had little impact on N concentration or removal NH4 and TKN concentrations decreased exponentially with increased residence time NO_3 concentrations were low at both influent and effluent No differences in concentrations with residence time observed Temperature dependant rate constants for ammonium and TKN developed fron data collected at one site could be used to predict concentrations at another site.
	5.63 2.81 1.88	4 8 12	11.8 × 1.1 × 0.45 × 0.5	Pilot scale SSF	Woolgrass *(Scirpus cyperinus)* & Cattail *(Typha latifolia)*	Septic tank effluent	NH_4^+ 44.4 Š 73.4% TKN 46.2 to 67.5%	

* l = length (m)
w = width (m)
d = depth (m)
n = porosity

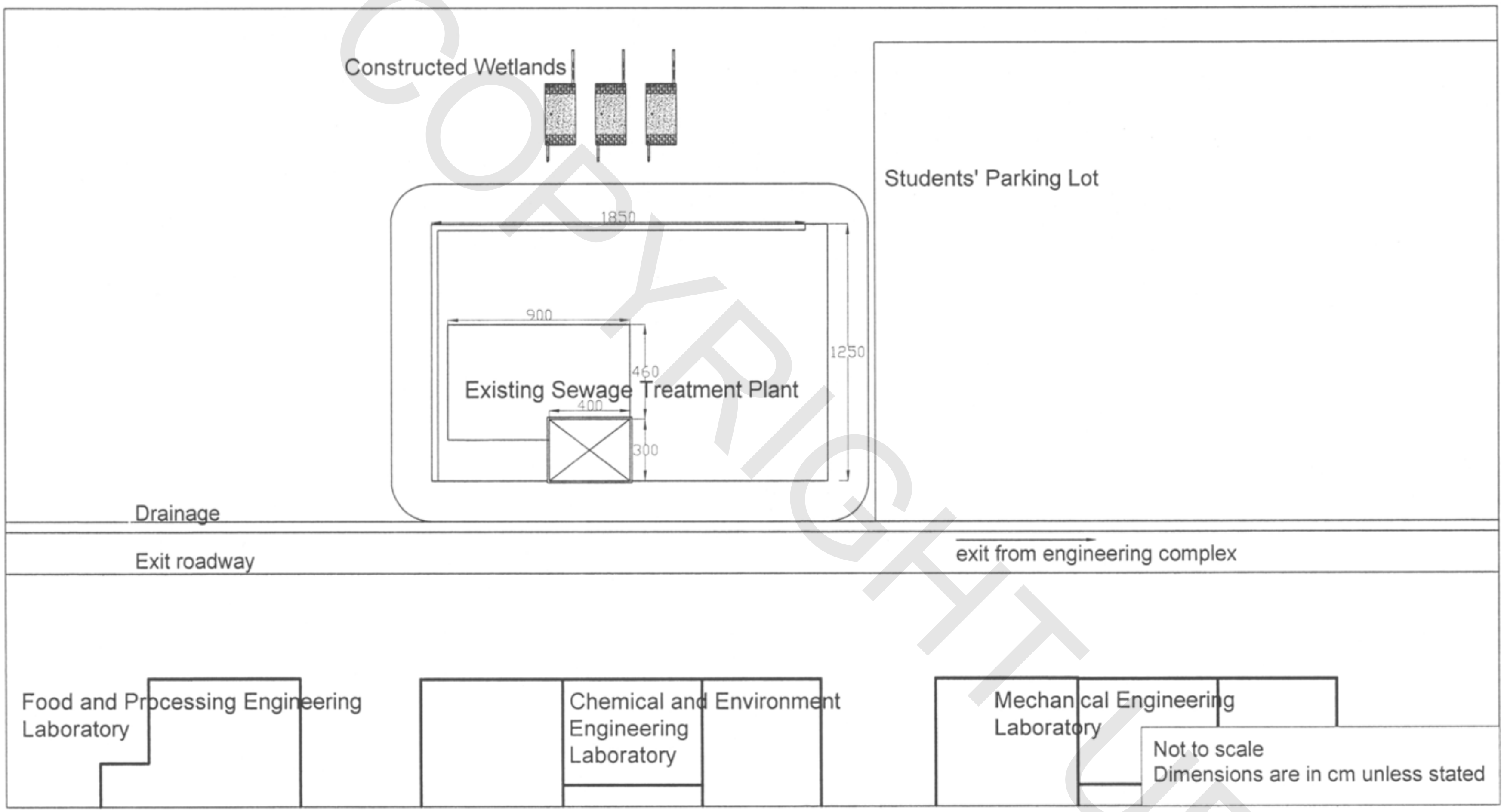

Figure 3.1 : Location of Constructed Wetlands

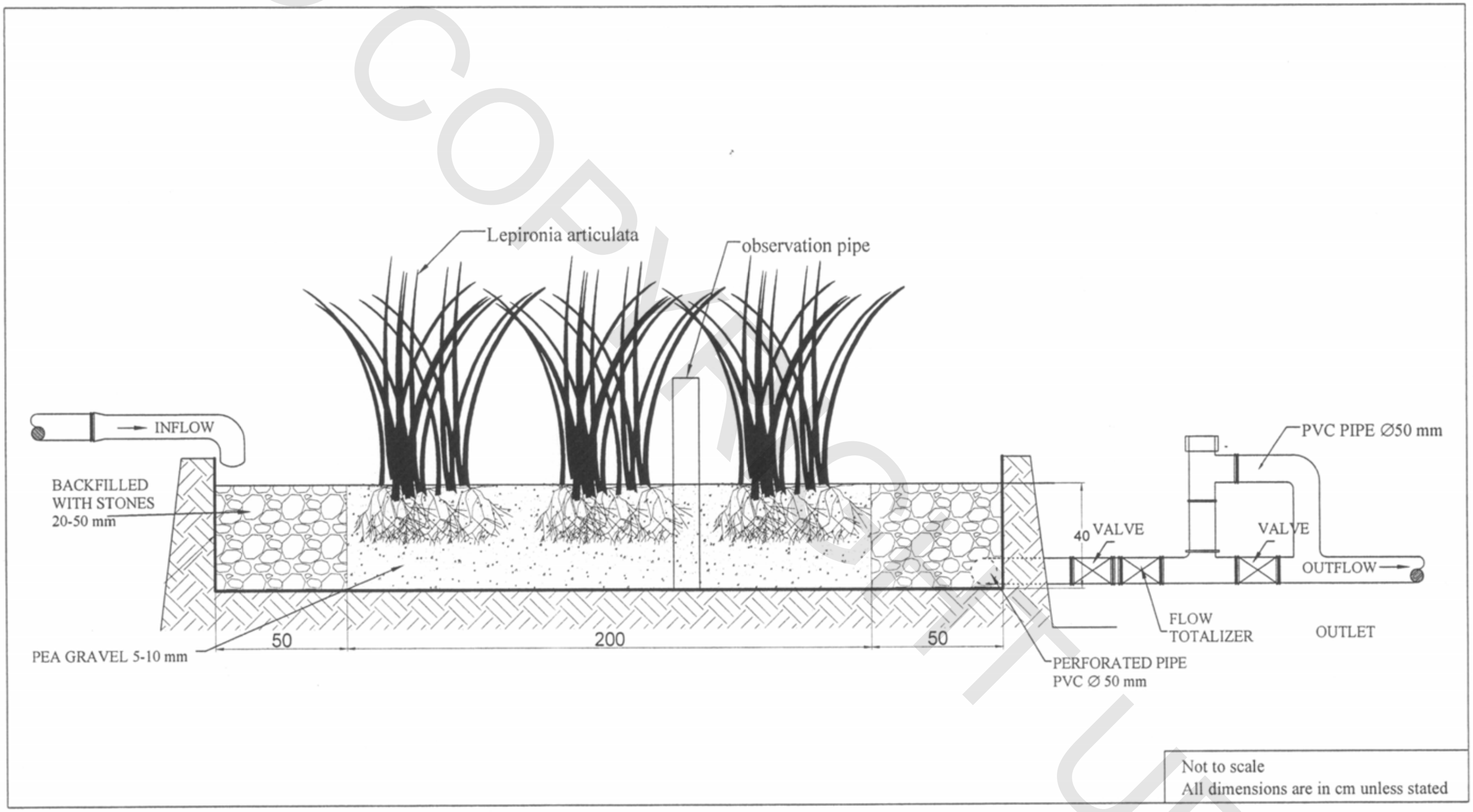

Figure 3.3 : Constructed Wetlands Design (Side View)

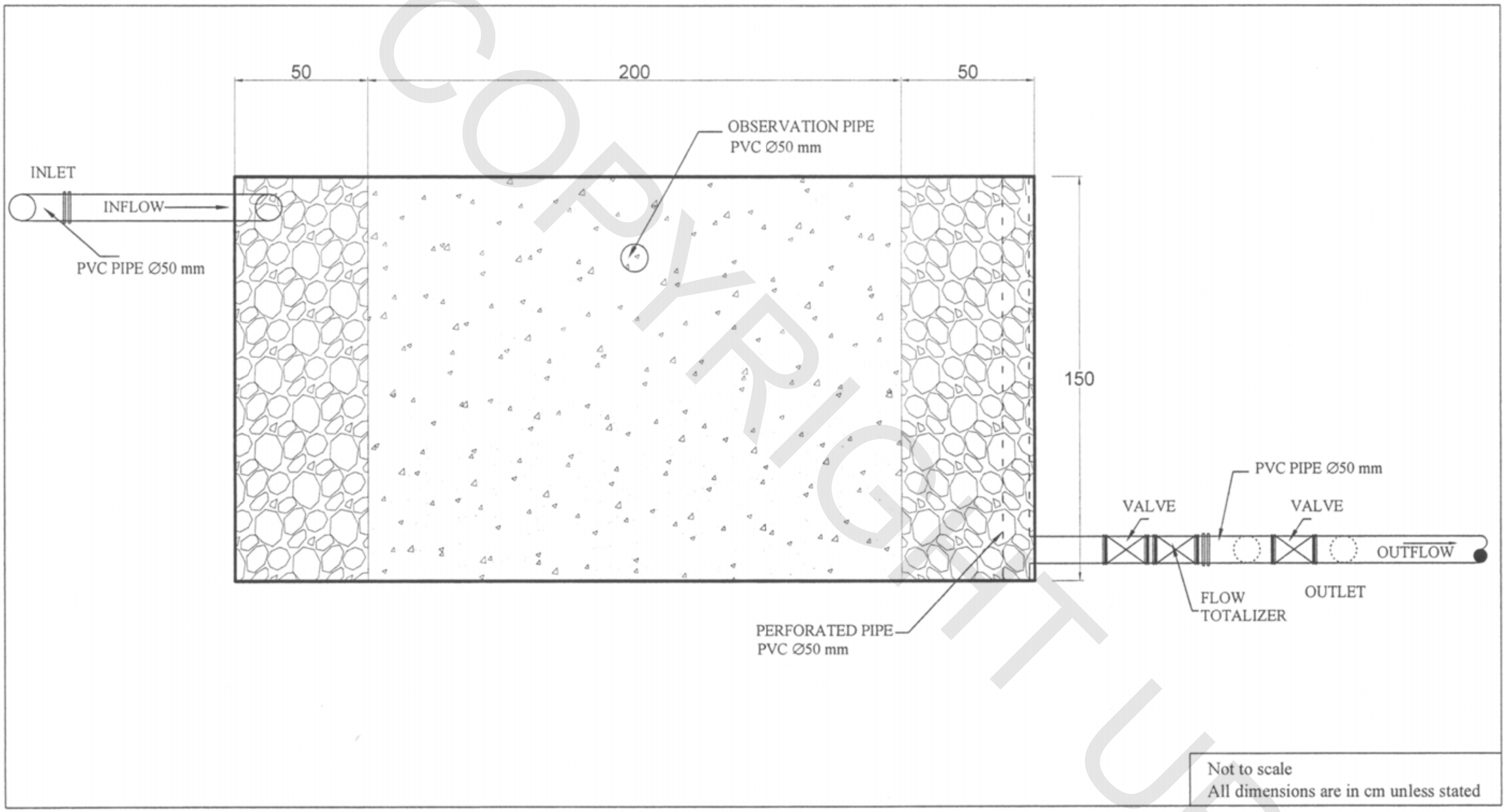

Figure 3.4 : Constructed Wetlands (Top View)

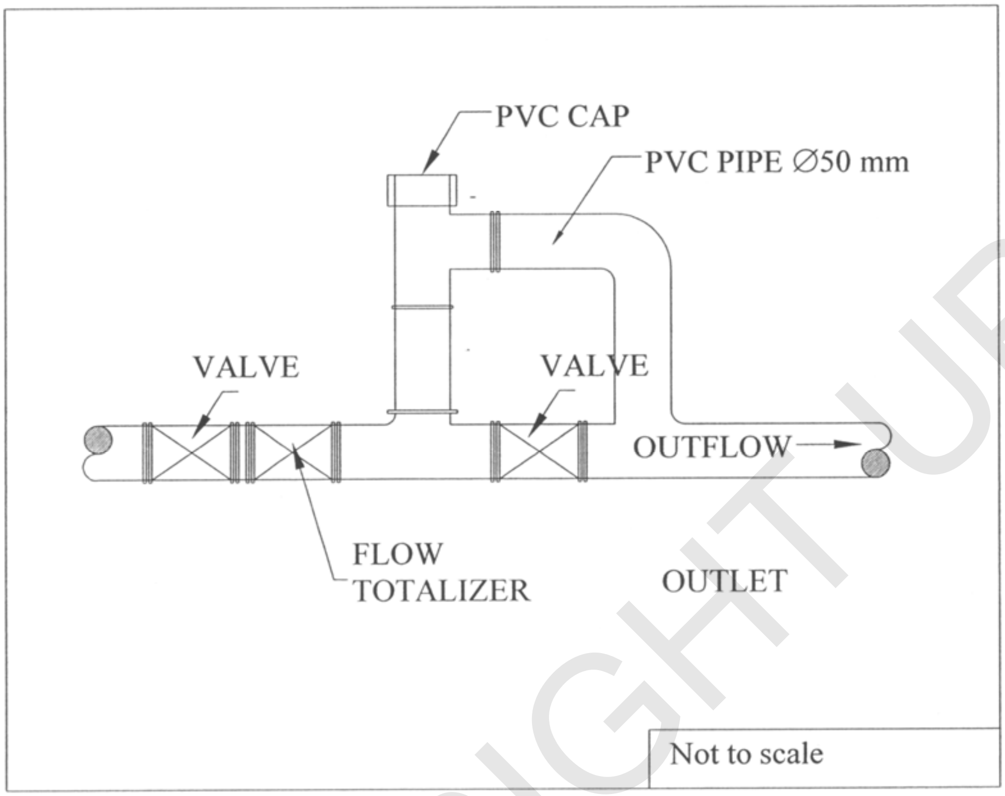

Figure 3.5 Outlet Structure of Constructed Wetland

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CHAPTER 1

INTRODUCTION

About 60 to 85% of the per capita consumption of water becomes wastewater (Metcalf and Eddy, 1991). Thus, it is expected that the amount of wastewater will increase along with the growth of population. It is commonly known that was tewater is harmful to human as well as the environment if it is not treated or disposed properly. Additionally, restriction should also be imposed on treated wastewater discharge where it should be made sure that the quality of the discharge does not harm the environment. Latest trend on river quality deterioration, especially those rivers in the catchments area for water supply, could also direct to another alarming serious problem which again, points to satisfactory wastewater treatment as the solution. A ccording to Malaysian Environmental Quality report (DOE, 2003) 18% of river basins were polluted by biochemical oxygen demand (BOD) due to sewage and 24% by ammoniacal nitrogen (NH_3-N) from sewage that included livestock farming and domestic sewage.

Domestic wastewater typically constitutes a combination of flows from toilets, baths, kitchen, sinks, garbage grinders, dishwasher, washing machines and water softeners. Domestic wastewater, as the name implies, principally originates in residence and is also referred to as sanitary sewage. As such, commercial, institutional, and industrial establishments contribute a domestic wastewater component to the sewer system resulting from human sanitary activity. Therefore domestic wastewater will typically contain mi neral and organic matter, including feces, urine, paper, soap, dirt, food wastes, minerals from water softeners and other substances. The constituents are usually grouped into physical, chemical and biological parameters. Concerning domestic wastewater, commonly measured physical parameters are solids and temperature. Chemical parameters are divided into organics and inorganics (pH, nitrogen, phosphorous) whilst biological parameters are microorganism indicators such as total coliforms, fecal coliforms and E-coli.

Many efforts have been done to treat and recycle wastewater so that the constituents will not harm the environment. Common wastewater treatment plants usually involved filtration, sedimentation and microorganisms degradation. Although all these process are parts of natural response, but the treatment system are supported by an often-complex array of energy-intensive mechanical equipment (Reed et al., 1988). In order to minimize mechanical elements, treatment by natural treatment system was suggest ed. The term natural system is used to describe those processes that depend primarily on their natural components to achieve the intended purpose. A natural system might typically include pumps and piping for waste conveyance but would not depend exclusively on external energy sources to maintain the major treatment responses (Reed et al., 1988).

Natural wetlands are one of the natural system treatments which have been used for wastewater treatment and polishing, however they suffer from some operational disadvantages including hydraulic control and vegetation management. Constructed wetlands (CW) are designed to overcome the disadvantages of natural wetlands. Constructed wetlands are receiving increased worldwide attention for wastewater treatment and recycling. Imitating natural wetlands properties, the constructed wetland created low energy, low cost, easy implementation and non-chemical wastewater treatment facility (Kivaisi, 2001). Moreover, they are more versatile over conventional systems and capable of treating more than one type of pollutants simultaneously. In addition the gains in vegetation biomass in constructed wetlands can provide economic returns when harvested for biogas production, animal feed, fibre for paper making and compost (Belmont et al., 2004).

Moreover, more usage of constructed wetlands appears to be, at least in part due to growing "green" environmental movement that supports more resources conservation and environmental protection, and greater reliance upon natural ecological processes and system in preferences to more energy and chemical intensive "mechanical" waste management systems. In the light of the above observation constructed wetlands are considered as a low cost, low-energy consumption, natural and sustainable wastewate r treatment system. Therefore, it is highly advisable to have such system to be used more in residential areas, hotels, offices and many other potential places.

Constructed wetlands system has been practiced widely in United States and some European count ries. However, to date application of constructed wetlands has not been emphasized in tropical countries. Tropic climate provides relatively constant temperature and non seasonal growing plants for the system to be expected to work all year. Malaysia as a tropical country should consider this as an advantage for implementing constructed wetlands. Some studies and practices on this system have been conducted in Malaysia, including in Putrajaya, Terengganu, Penang, Johor Bahru and Selangor (Jusoh et al., 2002 ; Noor et al., 2003; Lim et al., 2001; Sim, 2003). Most of the work reported in Malaysia have been in tank system and laboratory scale. Therefore, more studies should be carried out in Malaysia considering its great implementation potential.

While there a re many advantages of using constructed wetlands, not all designed constructed wetlands are success stories. There are things that can cause failure to the system during its operation, hence special attention is required in order to control those aspects. However, not much of those kinds of defects have been reported in the literature, but those identified are often related to the design, operation, maintenance and how they tallied with each other (Whitney et al., 2003).

In the implementation, a designed and constructed system would be difficult to change thus the operating condition should be adjusted to suit the system. In constructed wetlands, this adjustable operating condition would be loading rates and retention times. After the design and operating conditions have been set, the maintenance would contribute to the durability and efficiency of the system.

Appropriately calculated design would be needed, in addition to other considerations to be made in order to attain strong socialization of the cons tructed wetland application. There is a necessity to seek a simple design but yet functional constructed wetland for this purpose, as people will find it easier to apply, especially in small scale use in residential area, such as a simple unit of water tre atment for a